THEORETICAL FRAMEWORK FOR A MANAGEMENT DECISION EVALUATION SYSTEM

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Summary
A theoretical framework for a construction management decision evaluation system for project selection by means of a literature review. The theory is developed by the examination of the major factors concerning the project selection decision from a deterministic viewpoint, where the decision-maker is assumed to possess 'perfect knowledge' of all the aspects involved. Four fundamental project characteristics are identified together with three meaningful outcome variables. The relationship within and between these variables are considered together with some possible solution techniques.

The theory is next extended to time-related dynamic aspects of the problem leading to the implications of imperfect knowledge and a non-deterministic model. A solution technique is proposed in which Gottinger's sequential machines are utilised to model the decision process.

Sommaire
On propose ci-dessous, après une revue de la littérature un schéma théorique pour un systéme d'évaluation decisionnel de gestion dans l'industrie de la construction. La théorie est developpée en examinant les facteurs majeurs concernant les décisions relatives au projet, d'un point de vue déterministe. Le décideur est supposé posseder une connaissance parfaite de tous les aspects du problème. Quatre caractéristiques fondamentales sont établies avec trois conséquences variables. Les relations à l'initerieur et entre les variables sont considerées avec les solutions techniques qui en résultent. La théorie se porte alors plus loin pour examiner le problème sous l'aspect du temps, des repercussions de connaissances incompletes et pour développer un modèle non-déterministe. Une solution technique est proposee elle fait appel à des algorythmes de Gottinger en séquence pour modéliser la méthode de décision.

Keywords
Project selection, Bidding, Complex Dynamic Systems.

INTRODUCTION
Two of the most important, and yet most controversial, decisions made by a construction company are the type of work it wishes to undertake and a suitable price to charge for the work. In the competitive tendering situation, these two decisions are inextricably linked as

monetary aspects (eg liquid assets and cash) and non-monetary aspects (eg buildings, land, plant and equipment).

People
The extent to which people are affected by the decision process depends on their aspirations, expectations, attitudes and personal philosophies, sometimes termed 'values' (18). Recent studies indicate that the performance of tasks within the organisation fulfils some essential psycho-sociological needs of the individual (19).

Many factors have been associated with individual and group needs: activity, meaning, reward and social status (19). In the construction organisation context, non-monetary objectives such as "leisure" or "partaking in civic duties" (11), "maintaining a way of life" (15), "personal security" (11) and "serving the general community" (4) have been found. Attitudes to such objectives, however, would seem to be tempered by the current state of need fulfilment of the individual. The development states of an individual or group of people are not yet sufficiently understood to allow any universal classification, however. The widely used Maslow system, despite its drawbacks, does allow us to model the situation. One approach to gaining a measure of satisfaction in relation to the hierachy is by means of questionnaires which have been shown to produce at least ranked priorities (21, 30, 23).

Money
Monetary resources are usually classified into long and short term finance, long term finance being used to purchase buildings, plant and equipment to carry stocks of materials and short term finance to overcome immediate cash flow problems such as the purchase of materials, plant hire and payment of sub-contractors (13). The project selection decision will predominantly affect short term finance and usually only indirectly affect long term finance.

The acquisition of finance generates benefits (assets) and costs (liabilities). The liabilities incurred in the acquisition of finance consists of internal liabilities (eg debts owed to ordinary and preference shareholders) and external liabilities such as sums owed to debenture holders, the Inland Revenue (for taxes), banks (for loans and overdrafts) and trade creditors. Liabilities can also be short term (current liabilities) such as those payments to trade creditors, or long term (deferred liabilities) usually for more than one year (1). Assets can be similarly divided into current and fixed depending on the time period involved, a further relevant distinction being between liquid and illiquid assets.

Measures of monetary benefits are well established. 'Profit' and 'turnover' are of major interest, but several other descriptive statistics are commonly used including the ratios of current assets to current liabilities (working capital ratio), liquid assets to current liabilities and outstanding debts to sales (6).

Property
The extent to which property is directly affected by the project selection decision is often minimal, except perhaps in the case of

very large or unusual projects, as many effects are of a temporary nature. Some of the more permanent effects can be the need to increase the size of the head office to accomodate an expanding permanent staff, which may involve the acquisition of further land and buildings. Plant and materials are normally acquired for the duration of the project, although the residue of some large items of plant, such as a tower crane or batching plant, will have an impact. The acquisition of plant or manufacturing facilities for larger projects can have longer term implications in generating possible decision options involving permanent and separable business options.

Interrelationships in the outcome environment

Many aspects of the outcome environment are interrelated and often conflicting. A common feature is the clash of interest between power groups, such as senior management and unions, where changes in the environment which are beneficial to one group are detrimental to the other. Similarly improvements in levels of monetary resources of one group of people usually implies a reduction in monetary resources in another. The successful progress of the organisation depends exclusively on the balance of benefits received by these sections of the outcome environment.

Project characteristics

The characteristics of projects are necessarily a function of the construction industry itself. In examining the nature of industries generally, Smith has suggested key factors to be the type of products produced and the market served, the technology of production and the nature of the material required (28). The diverse nature of the construction industry, however, makes these factors rather difficult to define.

Hillebrandt defines the construction product as basically the service of moving earth and materials and of assembling and managing the whole process (15). However, as this service and management varies according to the technical processes involved, the industry is viewed as consisting of many sub-industries. A more appropriate analysis is proposed by Hillebrandt to be the *market*, in which a group of firms whose products are more or less substitutes for each other operates. Lange has termed these determinants, with the addition of 'industry branch', 'sub-markets' (20). Size, complexity and industry branch are often termed "type" or "size" and "type of work" (22).

The sub-markets - type of work, client, location and competitors - define the "nature of the work" (25). A recent study by the Building Economics Research Unit has found that these sub-markets collectively account for over 97% of the reasons underlying the decision to tender for projects (8).

The types of buildings are usually denoted by function: residential, commercial, industrial, educational and recreational being typical groupings. The physical and monetary size of a project affects the company's resources, particularly management and finance. Project size has been linked with productivity (7) and the development of managerial skills (14). Lansey et al have found that the technology of the project, expressed in terms of size, complexity and method of construction, significantly affects organisational and managerial aspects of the company, particularly when an unfamiliar technology is involved (21). 'Technology', however, although of potentially great value in expressing relationships between project characteristics and the outcome environment, has been found difficult to completely define and theoretical developments are still needed in this respect (21).

Four types of client have been identified - speculators, public bodies, occcupiers and monumentalists (17). Two main influences on outcomes have been found to be the "ability to pay" and "relations" (29). An important factor included under the general concept of client is that of procurement method and contractural arrangements.

Dressel distinguishes between "home" markets (consisting of town area, region, county, province and country) and "abroad" (consisting of neighbouring country, developing countries and overseas) (9). Familiarity with location, however, would seem to be a more important distinction. It has been found that most companies operate over a relatively small area, mainly within a maximum radius of forty miles from their home base. The distance of the project from the company's local base affects operatives, who appreciate short travel and the extra free time it produces (30). Local craft can, of course, be employed, but this often adversely affects productivity (9) and , hence, monetary resources. Further important factors are transportation costs and the effects on organisational structure in the need to make special communication arrangements.

From the market viewpoint, it is the company's competitors that determine the value of the project and, as the deterministic model presupposes that competitors' bids are known, then the project value must also be known. It is for this reason that the bidding problem viewed deterministically is essentially a project selection problem. The factors influencing bid levels will be the same as the company's factors. Ease of entry to the industry or market, for instance, simply reflects the position where the option to enter is associated with beneficial and preferential outcome.

<u>Interrelationships between project characteristics</u>

The four project characteristic groupings - type, client, location and competitors are not independent. Certain types of clients for instance always want certain types of buildings, or always build in the same locality. A complete model would accomodate possible relationships between type of location (eg. nuclear power stations should be on remote sites), competitors and clients (eg. the existence of a well established package dealer may influence the procurement type decision), competition and type (eg. a company's known ability to produce certain pre-fabricated components may influence the design) etc.

<u>Multiple criteria decisions</u>

The primary objective of the company has been said to be "in the continued existence and further development of the company" (9). This is often expressed in terms of the monetary objectives such as maximising profits, making adequate, normal, modest or target profits or minimising losses. Other objectives occur such as efficient utilisation of resources or enhancing the general well-being of the people involved. In all cases, it is clear that all these objectives prevail but with differing levels of emphasis.

In terms of the model described above this means that the decision-maker places differing levels of emphasis upon different aspects of the outcome environment. Irrespective of the emphasis, there is a need for the decision-maker to be informed of the consequences of his decision on these outcome environment aspects. This, of course, is determined by the relationships between the project characteristics and the outcome environment.

MacCrimmon has identified four major categories of solution techniques in multiple criteria problems of this nature - weighting methods, sequential elimination methods, mathematical programming methods and spatial proximity methods (24).

Examination of the construction industry literature reveals two approaches, both involving the formation of a global preference function. Fellows and Langford (10) give an example of a weighted additive multi-attribute utility function approach in considering five courses of action (outcomes) evaluated on five criteria . Adjustment for the relative importance of each criterion is made by a utility weighting device before values are summed into an aggregated "outcome evaluation". Under the reasonable assumption that the decision-maker is interested in maximising the utility of the various consequenses resulting from his decision, the 'best' decision is that associated with the highest aggregated outcome evaluation. Ibbs & Crandall (16) have considered the use of weighted additive and multiplicative multi-attribute functions. In their example are three decision options the outcomes of which are evaluated on three criteria. In this case the multiplicative formulation relies on the existence of Utility Independence (UI) and Multi Utility Independence (MUI) and tests are necessary to verify this assumption. Weighting factors are used for all attributes together with an attribute scaling factor and the resulting global preference function is computed for each decision to indicate the 'best' decision. The independence checks, involving all permutations of the criterion variables can become unwielding with more than five or six criteria but the technique appears to give a reasonable, if rather crude, indication of decision preference.

Time dependent aspects

The deterministic model concerns the selection of a project or a set of *simultaneous* projects which would best benefit the outcome environment without regard to any further selections that may be considered in the future. It is clear, however, that future decisions will be significantly affected by current decisions and *vice versa*. The problem can, therefore, be restated as that of selecting the set of *sequential* projects which will best benefit the outcome environment. Problems involving sequential decisions are said to be dynamical problems and the dynamical version of the project decision problem demands knowledge of the effect of the outcome environment associated with each project on the quantity and characteristics of future projects.

The generation of knowledge of project opportunities is normally regarded as being as a result of some marketing activity. The marketing aspects of the project selection decision, however, are only a small part of the total possible marketing effort and very little literature is available on the subject.

Time related implications also occur in the outcome environment. The impact of benefits received by people is, according to Maslow's theory, dependent on the stage of development reached at the time. In the case of human resources these benefits are received continuously resulting in continually changing developmental and aspirational states. Also, as people join and leave the organisation, fluctuations in quantity as well as quality occur. Performance levels are also affected by time, instanced by such phenomena as the learning curve. The time of the year can affect output by up to 50% (8) and construction sites are particularly vulnerable to difficulties in the co-ordination of sequential activities. Many other time effects are evident. The resistance and reluctance to change, the effect of change on the organisational structure of the company, cash flow, effects on physical property, post-contract design changes, etc.

Implications for evaluation and selection

Consideration of time related aspects of project selection introduces the notion that outcomes take place over time. These outcomes can be regarded as being discrete events or as continuously developing, as represented by discrete or continuous time systems. An outcome, in these terms, is effectively the state of the outcome environment *at some point in time* after the decision has been made. Points of time of interest depend on the circumstances, such as project duration for profit or monthly for cash flow analysis. Ideally, however, one would wish for continuous evaluation, that is, the system should indicate the state of the outcome environment *at any moment in time*. Similarly, the state of the *project generating environment* requires evaluation.

In the systems context changes in the environment can be regarded as an iterative process and any decision affecting these changes are termed 'adjustment processes'. One approach to modelling the complexities of the various interative elements in the decision environment over time has been a device termed a 'sequential machine' (12). The sequential machine is a finite-state dynamic system possessing five general characteristics - a set of inputs, a set of outputs, a set of states, a state transition function, and an output function. The perspective is to consider sequential machines as basic analogues for modelling complex 'humanistic' systems (organisations) and to treat adjustment processes in terms of transformation on the set of states of a machine. The first task in building such a machine is to decompose the system into component parts or sub-systems. This is done by first identifying the external state vector representing exogeneous factors driving the system from the outside. In terms of the project selection process, these exogeneous factors include such indirect influences as government policy and social attitudes. The next step is to decompose the remainder into three types of machine, a message machine, a decision machine and a pay off machine.

In terms of project selection this implies project opportunities and characteristics (message machine), project selection/rejection (decision machine) and the outcome environment (pay off machine). The project selection process is then, in terms of this model, controlled by the decision machine, the key developmental results being formed in the decision machine. The solution to the problem must then be operating the decision machine in such a manner as to obtain the 'best' set of developmental states.

NON-DETERMINISTIC PROJECT SELECTION MODELS

Imperfect knowledge

The model of the project selection decision process thus far developed relies on the decision-maker 'knowing' the exact effect of potential decisions on the outcome environment, placing some value on each of these effects and selecting the 'best' decision by comparing these values. In reality, however, 'exact' effects can seldom, if ever, be predicted and the difference between predicted and actual outcomes are a direct result of the imperfect knowledge of the decision-maker. The nature and magnitude of these differences have a significant impact on the problem. In fact the lack of perfect knowledge opens up whole areas of the project selection problem. As the decision-maker can no longer be regarded as having direct access to the 'real world' he must attempt to create an internalised version from his perception of that world. The closeness to which the internalised model alignes with the real world determines the quality of the model and, hence, the quality of the decisions. The degree of alignment is dependent on the contextually interdependent aspects of the modeller and the information received by the modeller.

Little is known of the abilities of the modeller except that experience, training and, perhaps, some inate characteristics are beneficial. Informational requirements are, on the other hand, rather better known. Information directly related to the problem is, however, never complete. Some kinds of information are either too costly to obtain or simply unobtainable. These practicalities dictate the need for relatively inexpensive information concerning the entire decision environment. Further issues centre on the accuracy and usefulness of information and its relationship with the decision-maker.

The total decision environment

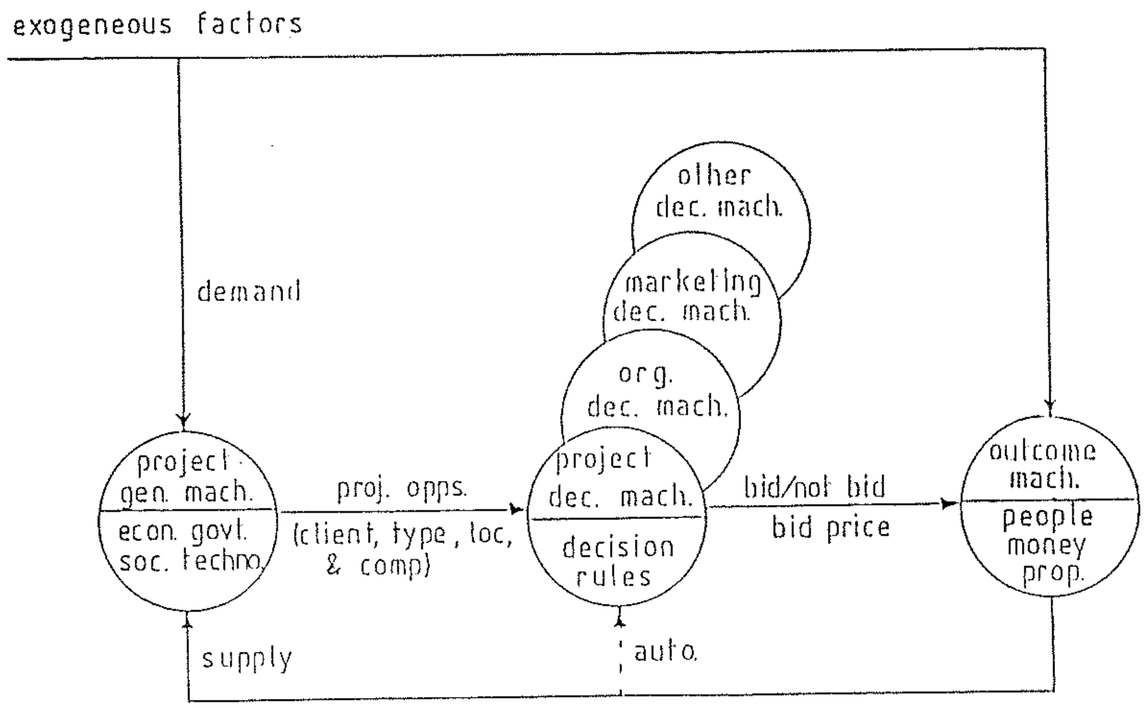
The insufficiency of knowledge relating to the central aspects of the decision problem demands that the informational net is cast around secondary and tertiary aspects of the problem. Insofar as the project generating environment is concerned these further aspects can be grouped into four general and interdependent areas of concern - economic factors including inflation, interest and exchange rates; political factors including the political ideology of the government and political developments on an international scale together with legal and legislative measures; social factors including changes in life styles and value, and technological factors including the impact of new technology on specific industries (3).

The accuracy of predictions relating to the project generating environment is not thought to be generally very good. There are, however, no specific figures available in the literature and some research in this direction, particularly in relation to project characteristics, the abilities of the predictor and information used would be advantageous. Accuracy in predicting the state of the outcome environment is known to be poor. Estimating construction costs is probably the most researched area and the process has been found, in practice, to be "very approximate and crude" relying on "haphazard" methods often "grossly in error" (26). Ashworth & Skitmore (2) have examined estimating accuracy in some detail. Their findings suggest that the extent of complexities and uncertainties in the process results in accuracy being determined more by the ability of the predictor than by the project information available. More recent experimental work by Skitmore (29) offers some convincing empirical confirmatory evidence in this respect.

Decision environment

The effects of imperfect knowledge is essentially two-fold. One factor is that uncertainties in the immediate decision environment introduce the necessity to consider more indirect influences. These indirect influences also result in consideration of other aspects including organisation and control together with marketing decisions. In terms of the sequential machine approach, this suggests a model along the lines of Figure 1.

Figure 1. The project decision system environment



Here the project decision machine is envisaged as being one of several such machines all causally related to the project generating machine and the outcome machine. The project generating machine consists of a set of our internal 'states', economic, governmental, societal and technological, which are determined by exogeneous variables such as government ministerial policy decisions, changing international economic conditions, shifts in societal attitudes and general technological developments, generally influencing the demand for construction work. Other determinants of the project generating machine states emanate endogenously from the outcome machine in what may loosely be termed as marketing inputs. The outputs of the project generating machine determine the frequency and characteristics of project opportunities for input into the project decision machine. The project decision machine output in the non-deterministic situation consists not only of the dichotomous project selection variable, but also of other features which may determine project acquisition, such as the price and contract duration offered. The result of the project decision, together with such exogeneous factors as societal aspirations, interest and inflation rates, forms an input into the outcome machine affecting its three states of people, money and property. The connection between the outcome machine and the project generating machine forms the dynamical link in the system and the control link (shown dotted in Figure 1) suggests a means by which the decision machine can be automated to respond in a rational manner to changes in outcome states.

The second factor turns on the predictive difficulties associated with the system components. The five general characteristics of each machine, inputs, outputs, internal states, state transition and output functions, have some degree of unpredictability, usually extremely high. The way in which environmental changes affect project opportunitites is largely unpredictable and little appears to be known of the effect of project characteristics on the state of personal well being. Perhaps the most knowledge that is available concerns the effect of project characteristics on monetary outcomes, although there is still a considerable degree of uncertainty involved. These predictive difficulties are further exacerbated by the need to forecast future events, preferably over a period of several years.

The situation is, however, not entirely hopeless. One of the great contributions of J von Neumann is to have proved the fact that a predictable system can be built from unpredictable parts. An outstanding example of this is the construction project simulator (CPS) which, by repeated simulation of stochastic construction process model containing many highly varying elements, generates fairly stable probability distributions of project cost and duration (5). The CPS typifies what is termed dynamic systems of "intermediate complexity". Gottinger outlines four points on which he would like to see computer models developed in order to cope successfully with systems of intermediate complexity. Firstly, the model should be aimed at achieving improvements rather than optimality. Secondly, sensitivity analysis should be preferred to formal statistical hypothesis testing. Thirdly, the computer model should consist of an interaction between human beings and machines. And, finally, the system should be integrated as far as possible with other similar such systems. These recommendations clearly define the direction of future research and development in major management decisions of the type considered in this paper.

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